

Aerobic rice cultivation

for enhanced water use efficiency

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The increasing shortage of water resources has led to the development and adoption of aerobic rice system, which saves water input and increases water productivity by reducing water use during land preparation and limiting seepage, percolation, and evaporation. Aerobic rice also reduces labour requirement and greenhouse gas emission from rice field. Aerobic rice cultivars are adapted to aerobic soils and have higher yield potential than traditional upland cultivars. Grain yields of 5 to 6 tonne/ha can be reached in aerobic rice system.

Key words: Aerobic, Cultivation, Rice, Water use efficiency

RICE (*Oryza sativa*) consumes the highest amount of water to produce per unit amount of dry matter (i.e transpiration coefficient). It consumes around 3,000 to 5,000 litre water to produce 1 kg dry matter. Now the question is whether we will be able to produce the required quantity of food with available water? The answer is yes but, for that we need to be judicious while applying the irrigation water to crops to maximize the yield and minimize the losses of water in the field. Farmers are seeking alternate methods of cultivation for growing rice to combat this water scarce situation concurrently climate change too. The crucial strategy to address this challenge of water shortage is producing more food for each drop



Fig. 2. Aerobic rice variety



Fig. 3. Traditional rice variety.

of water. One such method is the cultivation of rice under aerobic situation which is characterized by aerated soil environment during the entire period of crop growth.

Aerobic rice production is a revolutionary way of growing rice in well-drained, non-puddled, and non-saturated soils without ponded water. This system uses input-responsive specialized rice cultivars and complementary management practices to achieve at least 4 to 6 tonne/ha using only 50 to 70% of the water required for irrigated rice production. Chronological study showed that the genesis of aerobic rice is in China, but the name was given by

International Rice research Institute (IRRI), Manila, Phillipines. Aerobic rice is specifically developed rice, combining drought tolerance of upland rice and yield potential of lowland rice. The aerobic rice is 'improved upland rice' in terms of yield potential and 'improved low land rice' in terms of drought tolerance. It is a rice growing in aerobic soil, with the use of external inputs such as supplementary irrigation, fertilizers and aiming at high yields. Aerobic rice is the best remedy for future climate change under drought condition with lesser greenhouse gas (GHG) emission. Due to unsaturated conditions, there is possibility that aerobic rice emits lesser methane (CH₄) gas into the atmosphere, thus keeping the environment safe besides water saving.

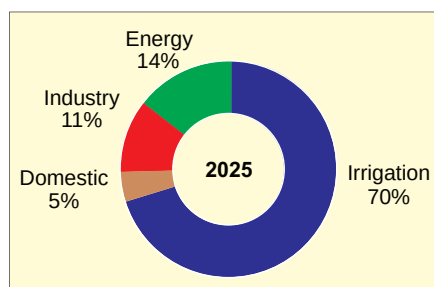


Fig. 1. Annual water availability by 2025 for different sectors

Aerobic rice is recommended in areas where water has become too scarce or expensive to grow flooded rice, and in rainfed areas where rainfall is insufficient for flooded rice production but sufficient for upland crops. An area facing labour shortage and higher labour wage problems.

Regions which may face water and labour shortage in the future

In the north-west Indo-Gangetic plains of India, increasing use of groundwater for rice cultivation has led to a decline in the water-table by 0.1 to 1.0 m/year, resulting in water scarcity and increased cost for pumping water. Implementation of the Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA), introduced by the Indian Government in 2005, promising 100 days of paid work in people's home village, has been creating a labour scarcity in Punjab as rice transplanting in this region is dependent on migrant labours from eastern Uttar Pradesh and Bihar. Thus, aerobic rice is now considered to be an emerging production system in the north-west of Indo-Gangetic plains of India.

MANAGEMENT OF AEROBIC RICE

Crop establishment

Along with high water requirements, the traditional system of transplanted rice production in puddled soil at long run leads to destruction of soil aggregates and reduction in macro-pore volumes, and to a large increase in micro-pore space which subsequently reduce the yields of post-rice crops, eg. wheat. Obtain a smooth seedbed before dry direct seeding by ploughing and harrowing. Smooth seedbed essential for better seed germination and seedling establishment. Seeds are sown at a depth of 1 to 2 cm in heavy soil (clay) and 2-3 cm depth in light texture soil (sand and sandy loam). Sowing can be done in two ways: (i) by dipping the seeds manually into the slits opened by a stick or tooth harrows; (ii) mechanically using direct seeding machine (drum seeder). The optimum seeding rate is



Fig. 4. Pora method of sowing of aerobic rice



Fig. 5. Pendimethalin spray in the field of aerobic rice

between 40 and 45 kg/ha. Maintain between 20 and 25 cm row spacing.

Irrigation

Aerobic rice is non-flooded and irrigated similar to other crops in water scarce environments and can stand periodic flooding conditions. In China, the irrigation water requirement for lowland rice is about 1,590 mm per season, while for the aerobic rice, it is around 400-700 mm per season or less. Aerobic rice could save more than 50% water and its water productivity is 60% higher than transplanted rice.

Irrigation is scheduled at 5-7 days to bring the soil moisture to field capacity in top 20 cm soil depth. Such water management is also known as AWD (alternate wet and dry), and the soil is partially aerobic during most of the growing season. Irrigation can be given through flooding or sprinkler. The amount of irrigation should be enough to maintain the soil moisture condition at field capacity and soil moisture potential between 30 and 40 KPa or 0.3-0.4 bar. Some visible signs that the soil moisture is below field capacity are hair-line cracks in the soil and rolling of the tips of leaves. Light irrigation (30 mm) after sowing may be needed to promote emergence. The different planting systems on rice

crop (saturated soil culture and intermittent irrigation) showing clear evidence of reduction in total water use in aerobic rice cultivation than the other irrigated and upland condition which are using more water. Water requirements can be lowered by reducing water losses due to seepage, percolation, and evaporation (Table 1).

As land preparation, puddling, transplanting, and irrigation activities require maximum percentage of total labour, exclusion of these practices in aerobic rice no doubt saves a major portion of labour too. Besides aerobic rice system emits lesser amount of methane (CH_4) gas into the atmosphere due to unsaturated condition. Thus keeping the environment safe besides saving water. But at the same time alternate wetting and drying, increase denitrification, which leads to higher emission of nitrous oxide (N_2O) and lower nitrogen use efficiency.

Fertilizer management

General recommended dose of NPK is 120:50:50 kg/ha to a yield goal of 4 to 6 tonne/ha. The site-specific nutrient management (SSNM) approach is recommended to determine the need for supplemental nutrients. One useful tool under SSNM is the use of the

Table 1. Water requirement comparison between lowland flooded rice and aerobic rice

Particulars (seasonal water requirement)	Lowland flooded rice (mm)	Aerobic rice (mm)
Land preparation	150-300	100
Evaporation	200	100
Transpiration	400	400
Seepage and percolation	500-1500	335
Application loss (at 60% efficiency)	-	335
Total seasonal water requirement (mm)	1650-3000	935

Table 2. Identified aerobic rice varieties

Country	Rice variety/breeding line	Yield
China	Han Dao 297, Han Dao 502, Han Dao 277	6 tonne /ha
India	MAS 946-1, MAS 26	>4 tonne /ha
Laos	B6144F-MR-6-0-0 3.	6 tonne ha
Philippines	Apo (PSBRc9), UPLRi5, PSBRc80	5-6 tonne ha
Parameters	Description of rice varieties	
Rice variety	SHARADA (MAS 946-1)	
Average Yield	5–5.5 tonne /ha	
Maturity	Medium duration	
Characteristics	Zone- 5, eastern dry zone of Karnataka. Plant height : 110-112 cm, it is medium duration variety matures in about 125 days. Plants have thick stem and erect plant type. It is drought and blast disease tolerant. Profuse rooting, high tillering and grains are medium slender. Variety is suitable for both <i>kharif</i> and summer. Irrigation once in 5-7 days until flowering and once in 3 days at flowering and grain filling stage. The grain yield is 6 tonne/ha and fodder yield 6 tonne/ha	
Rice variety Name	ONA SIRI (MAS 26)	
Average Yield	4 to 5 tonne /ha	
Maturity	Early duration variety.	
Characteristics	Zone 4 and 5 of central dry zone and eastern dry zone of Karnataka. Plant height: medium tall, it is early duration variety matures in about 120 days. Panicles are bunches. Root length can grow up to 1 m under moisture stress. It is drought and blast disease tolerant. Profuse rooting, high tillering and grains are medium slender. The grain yield is 5 tonne/ha and fodder yield 5.5 tonne/ha irrigation once in 3 days at flowering and grain filling stage.	

leaf colour chart (LCC) to assist in the application of nitrogen (N) fertilizer. In absence of knowledge or training on SSNM, farmers can initially apply 70 to 90 kg N/ha in three splits. The first split should be applied 10 to 12 days after emergence to minimize N losses from leaching. The second split should be applied at active tillering and the third split at panicle initiation. Note that a basal N-fertilizer application promotes early weed growth. Thus exclusion of basal application of nitrogen helps in minimizing weed pressure. Dry, aerobic soil can reduce the indigenous supply of phosphorus (P) and iron (Fe). Thus the application of P and Fe fertilizer is more critical for aerobic rice production than for conventional flooded rice production systems. The use of phosphorus solubilizing bacteria's like *Pseudomonas striata* and *Bacillus polymixa* and fungi like *Aspergillus awamoori* and *Penicillium digitatum* increases indigenous supply of phosphorus. In India inoculum of phosphate solubilizing micro-organism (PSM) is in the market as microphos, phospho-bacteria and superphos. It is adequately established that the efficiency of

inorganic fertilizer can be greatly increased through its integration with phosphorus solubilizing micro-organisms. Iron deficiency is most commonly realized problem in an aerobic rice system in most part of the country. As the availability of iron under the aerobic dry soil is limited due to oxidation of ferrous (Fe^{2+}) to ferric (Fe^{3+}), which is available to plants. Though Indian soils are rich in iron content, the major portion of iron remains unavailable to crop plants. Recommended measure is a foliar spray of 2% iron, partial flooding of the land. Fe concentration in aerobic rice grain and straw recorded significantly higher with three foliar sprays of 2% FeSO_4 at maximum tillering, pre-flowering and flowering stages of rice growth. Brown manuring also increases availability and uptake of Fe by creating anoxic condition.

Weed management

Aerobic soil dry-tillage is conducive to the germination and growth of weeds. Thus, weed infestation is a major constraint in aerobic rice production and timely weed management is of paramount importance to increasing the

productivity of aerobic rice. Aerobic rice is as good as transplanted rice, if weeds are controlled effectively. In the early phase of crop growth herbicides are recommended for weed control, if weed pressure is high. Pre-emergence herbicide application pendimethalin/oxadiazon or post-emergence herbicide (bispiribac sodium) and manual weeding are recommended. Normally pre-emergence application of herbicide followed by hand weeding found more effective. Brown manuring is another best option for early season weed control. Brown manuring is no-til version of green manuring. *Sesbania* crop is seeded together or three days after rice sowing as intercrop and allowed to grow for 30 days. Subsequently *Sesbania* intercrop is knocked down with 2,4-D at 500 g/ha. After killing colour of *Sesbania* residue become brown, so it's called brown manuring. *Sesbania* while growing with rice smother weed to a great extent, reduce herbicide use and supplies 15 to 20 kg N/ha.

Limitation in aerobic rice cultivation

In Asia, 'upland rice' is already grown aerobically with minimal inputs in the upland environment, but mostly as a low-yielding subsistence crop to give stable yields under the adverse environmental conditions of the uplands. Comparison of agronomic performance of aerobic and flooded rice in tropical areas confirmed a yield gap between aerobic and flooded rice. However, the yield loss of aerobic rice could outweigh the benefits of its water savings. Aerobic rice cultivars are adapted to aerobic soils and have higher yield potential than traditional upland cultivars. Grain yields of 5 to 6 tonne/ha can be reached in an aerobic rice system. The major limitation in aerobic rice cultivation, in comparison to irrigated rice is, its lower grain yield. Research studies showed that average grain yield is 32% lower in the aerobic conditions than in the flooded conditions in the dry season (December to May) and 22% lower in the wet season (June to November). Thus yield reduction is

more in a dry season than wet season. Yield decline or even complete failure of aerobic rice threatens the widespread adoption of aerobic rice technology. The possible causes for declining yield of aerobic rice are: both biotic (weeds, nematodes) and abiotic factors (soil pH increase, ammonia toxicity, and nutrient deficiencies like P and Fe).

One of the ways to narrow the gap may be through development of rice varieties that are more adapted to aerobic conditions. India did not lag in the development of aerobic rice cultivars and the country has currently two varieties to her credit which are also drought resistant, MAS 946-1 rice developed in March 2007 and MAS 26 rice in 2008 both being developed by University of Agricultural Sciences, Bangalore. The yield from these varieties seemed to be on par with the flooded lowland varieties with an average of 5.5 to 6 tonne/ha and required 60% less water (Table 2). The problem is that upland rice varieties have lower productivity while lowland varieties were found to have a bounteous harvest only under flooded field conditions. For this purpose new varieties have to be bred, and IRRI has decided to term these new varieties bred as aerobic rice. The series of these cultivars of rice will be having the ability to grow like dry land cereals like maize and wheat and have productivity like lowland cultivars. These rice cultivars will be watered by using either rainfed or irrigation technologies without the need to puddle the field.

Rice rootknot nematode in aerobic rice cultivation and its management

Rice root-knot nematode, *Meloidogyne graminicola*, is one of the most predominant pest associated with rice under upland condition and cause substantial yield losses. More than a decade, farmers depend on chemical nematicides (carbofuran) for the control of plant parasitic nematodes and a remarkable reduction of nematode population was achieved. Although soil nematicides are effective and fast-acting, they are currently being

reappraised with respect to the environmental hazards and human health. Besides they are relatively not affordable for many small-scale farmers. Hence an eco-friendly and environmentally safe technique is aimed incorporating bio-agents in the management of root knot nematode under field conditions. Bio-agents like *Trichoderma viride*, and *Pseudomonas fluorescens* improved the plant growth and reduced the nematode infestation in aerobic rice. Biological control of plant parasitic nematodes is regarded as an important component of the integrated nematode management system and it acts as an alternative to various chemical pesticides due to their self-sustaining action.

Advantages

Advantages of aerobic rice cultivation are as follows:

- Contribute to country food self-sufficiency by stabilizing the production.
- Saving of water up to 60% through exclusion of puddling and land submergence.
- Needless labour than transplanted rice as nursery preparation and transplanting is not required.
- Reduced seed rate leads to saving of seed and seed cost.
- Less pest/disease incidence.
- Reduced methane emission leading to lower environmental pollution.
- Easy to establish the crop (dry direct seeding).
- Retention of soil structure and quality by evading puddling operation.
- Good alternative to other upland crops (eg. maize) in the event of flooding.
- Reduced cost of cultivation.
- Efficient fertilizer utilization.
- Reduction in total duration of crop.
- Facilitate timely sowing of wheat crop in RWCS.

Constraints

Constraints in aerobic rice cultivation are as follows:

- Lower grain yield compared to lowland rice.
- Improper crop stand establishment due to higher seedling mortality.

- Lack of suitable cultivars/varieties.
- Heavy weed infestation and difficulties in controlling weeds.
- Nutrient deficiencies like P, Fe, and Mn.
- Change in insect pest/diseases problem (e.g. Root-knot nematode).
- Limited knowledge about availability of appropriate herbicides.
- Lodging of crop due to shallow root system.
- Non-availability of quality fertilizer-drills.
- Lack of awareness or limited extension programmes.

SUMMARY

Overall aerobic rice technology is a promising technology that can stir up another green revolution by increasing productivity of rice using less water and direct sowing and therefore requiring less seeds, less labour, less greenhouse gases (methane) and efficient fertilizer utilization. Comparison of agronomic performance of aerobic and flooded rice in tropical areas confirmed a yield gap between aerobic and flooded rice. The possible causes for declining yield of continuous aerobic rice are: improper crop stand due to higher seedling mortality, heavy weed infestation, nutrient deficiencies (P, Fe), root-knot nematode infestation and unfavourable soil environment for semi-aquatic plants. The concept of aerobic rice holds promise for farmers in water-short irrigated rice environments where water availability at the farm level is too low or where water is too expensive to grow flooded lowland rice. Selection of good aerobic rice variety with desired physiological attributes along with good cultural practices, nutrient management practice, weed control measure, crop rotation, and brown manuring would give better performance.

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